33

EVALUATION OF SUBTITLE D LANDFILL DESIGNS USING THE HELP AND MULTIMED MODELS

ADDENDUM

Submitted to:

Office of Solid Waste
U.S. Environmental Protection Agency
Washington, D.C. 20460

Submitted by:

Science Applications International Corporation
1710 Goodridge Drive
McLean, Virginia 22102

EPA Contract No. 68-W2-0027
SAIC Project No. 01-0828-07-1749-000

Submitted June 30, 1995

TABLE OF CONTENTS

1.0 Introduction 1
- 1.1 Purpose of This Addendum 1
- 1.2 Overview of the HELP Model 1
- 1.3 Overview of the MULTIMED Model 2
- 1.4 Application of HELP and MULTIMED to Subtitle D Landfill Facilities 2

2.0 The HELP Model 4
- 2.1 Selection of Model Input Parameters 4
  - 2.1.1 Climate Data 4
  - 2.1.2 Landfill Layer Data 5
  - 2.1.3 General Layer Properties 5
  - 2.1.4 General Simulation Data 11
  - 2.1.5 Modifying Model Inputs 12
- 2.2 Interpreting Model Output 12
  - 2.2.1 Average Monthly Output Values 13
  - 2.2.2 Average Annual Output Values 13
  - 2.2.3 Peak Daily Output Values 14
  - 2.2.4 Final Water Storage 14
  - 2.2.5 HELP Output Used as MULTIMED Input 14
- 2.3 HELP Model Configurations for Specific Landfill Configurations 14
  - 2.3.1 Modeling More Than 5 Years of Landfill Infiltration 14
  - 2.3.2 Modeling Synthetic Liners That Are Not Part of Composite Liners 18
  - 2.3.3 Modeling the Influence of Landfill Geometry 18
  - 2.3.4 Modeling Geosynthetic Clay Liners (GCLs) 20
  - 2.3.5 Modeling Landfill Covers 20
- 2.4 Alternative Methods for Calculating Liner Infiltration Rates 21

3.0 The MULTIMED Model 22
- 3.1 Existing Guidance on the Use of MULTIMED 22
- 3.2 Questions Regarding MULTIMED Model Input for Evaluating Landfill Permit Applications 22
  - 3.2.1 Steady-State Source vs. Finite-Source Assumption 23
  - 3.2.2 Modeling the Unsaturated Zone 26
  - 3.2.3 Chemical Decay/Biodegradation/Sorption Coefficients 26
  - 3.2.4 Limitations of the MULTIMED Model for Low Hydraulic Conductivity Aquifers 27
  - 3.2.5 Use of Monte Carlo Simulations 28
  - 3.2.6 Use of Total vs. Net Precipitation to Determine Ground-Water Recharge Rate 29
- 3.3 Interpreting MULTIMED Results – Use of the Dilution/Attenuation Factor (DAF) 29
  - 3.3.1 Use of Site-Specific Leachate Data 29
  - 3.3.2 Use of Statewide Average Values or EPA Summary of Nationwide Data 30
  - 3.3.3 Using Detection Limits vs. Detectable Concentrations 30

TABLE OF CONTENTS

4.0 Conclusion 31

REFERENCES 32

1.0 Introduction

1.1 Purpose of This Addendum

The Solid Waste Disposal Facility Criteria (40 CFR Part 258) provide many areas of flexibility to landfill owners/operators and State/Tribal programs, including the use of alternative landfill liner designs. In April, 1992, the EPA provided basic guidance on the use of the Hydrogeologic Evaluation of Landfill Performance (HELP) and Multimedia Exposure Assessment Model (MULTIMED) models to evaluate alternative landfill liner designs. The HELP model is used to estimate the leachate infiltration rate from the bottom of the landfill, while the MULTIMED model is used to estimate contaminant transport from the landfill to the relevant point of compliance (POC).

The report describes the experiences gained from the use of alternative landfill liner designs in two situations. First, a State/Tribe seeking EPA approval of a permit program that allows the use of a statewide alternative landfill liner design. In this case, the review consisted of an evaluation of the the State/Tribal determination that a specific design meets the liner performance standard [§258.40(a)(1)] on a statewide basis. The second situation required the evaluation of site-specific alternative liner designs in unapproved States/Tribes. The landfill regulations [§258.40(e)] allow owners/operators in unapproved States/Tribes to use an alternative liner design via a "petition process". This petition process allows the State/Tribe to approve the alternative design, then petition EPA to approve the design. If the EPA does not respond within 30 days, the design is automatically approved. EPA issued a draft guidance memorandum that provided a framework for this process on September 20, 1993.

Implementing these requirements has provided EPA with a substantial amount of experience in evaluating landfill liner designs using the HELP and MULTIMED models. These evaluations have been conducted both for state program approvals and for individual landfill petitions in unapproved States/Tribes. During these evaluations, the EPA has encountered a wide variety of landfill liner designs and hydrogeologic regimes that required customized modeling approaches and model inputs. This guidance is based on the lessons learned during these evaluations and is intended to assist States, Tribes and landfill owners/operators in the proper application of the HELP and MULTIMED models to specific designs.

Chapter 2 of this guidance provides information on the application of the HELP model, and Chapter 3 provides information on the MULTIMED model.

1.2 Overview of the HELP Model

The Hydrogeologic Evaluation of Landfill Performance (HELP) computer program is a "quasi-two-dimensional hydrogeologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane, or composite liners. HELP was developed to conduct water balance analyses of landfills, cover systems, and solid waste disposal and containment facilities." (Schroeder, et al., 1994a). The EPA uses the HELP model to estimate infiltration through landfill liners as part of the evaluation to determine whether alternative liner designs meet the Subtitle D performance standard [§258.40(a)(1)]. The HELP model, Version 2, was made available in 1988;

in December, 1994, Version 3 of the model was released. Version 3 represents a significant improvement of the HELP model data entry interface and adds more flexibility to the types of data that can be entered into the model. For a complete description of the model use and of the engineering concepts on which the model is based, see Schroeder, et al. (1994a and 1994b). Copies of HELP Version 3 are available from:

US EPA ORD
Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7871

1.3 Overview of the MULTIMED Model

The EPA Multimedia Exposure Assessment Model (MULTIMED) "simulates the transport and transformation of contaminants released from a waste disposal facility into the multimedia environment. MULTIMED uses analytical and semi-analytical solution techniques to solve the mathematical equations describing flow and transport. The simplifying assumptions required to obtain the analytical solutions limit the complexity of the systems that can be represented by MULTIMED. The model does not account for site-specific spatial variability, the shape of the land disposal facility, site-specific boundary conditions, or multiple aquifers and pumping wells" (Sharp-Hansen, et al., 1990). The EPA uses MULTIMED to evaluate subsurface transport and transformation (i.e., hydrolysis, biodegradation) of contaminants released from Subtitle D landfills. Because the Agency uses representative state-wide conditions as model input, the site-specific limitations of MULTIMED have no effect in evaluating state program applications. In the event that representative data are not available for a particular input parameter, landfill owners/operators should use conservative assumptions intended to provide a "worst-case" estimate of potential contaminant concentrations in ground-water at the POC.

For a complete description of the use of MULTIMED and of the concepts on which the model is based, see Sharp-Hansen, et al., 1990, and Salhotra, et al., 1990. Basic guidance for applying the HELP and the MULTIMED models to Subtitle D landfill designs has been provided in a tutorial (U.S. EPA, 1992). The purpose of that tutorial was to allow inexperienced users to become familiar with the models and their application to evaluating landfill designs. The tutorial also provides an example of the application of the models, including example input data, to evaluate a hypothetical composite landfill design. In addition, EPA published a supplement entitled "User Manual Supplement: Using MULTIMED to Evaluate Subtitle D Landfill Designs" (Allison, 1993). This User Manual Supplement provides a description of the modules within MULTIMED, the steps to follow in evaluating a landfill design, and two examples of landfill design evaluations.

1.4 Application of HELP and MULTIMED to Subtitle D Landfill Facilities

The HELP and MULTIMED models can be used in tandem to evaluate alternative landfill liner designs. The HELP model is used to estimate infiltration rates from the bottom of the landfill. The MULTIMED model is used to estimate contaminant attenuation in the subsurface as the landfill leachate migrates to the POC.

All of the HELP output must be evaluated to determine whether the model has been applied correctly by the user and whether the conceptual model that the user develops for the HELP model

inputs is correct. However, only two of the HELP model output values are used as input to the MULTIMED model: the infiltration rate and the precipitation rate (which is used to compute the ground-water recharge rate required as input to MULTIMED).

The MULTIMED model uses the infiltration rate and ground-water recharge rate, as well as estimates of other model input parameters, to provide an estimate of the concentration of a contaminant at the POC. If a model user enters 1 as the concentration in landfill leachate exiting the bottom of the landfill, then the reciprocal of the predicted concentration at the POC is the dilution attenuation factor (DAF). Unless only one or two particular contaminants are of concern, the EPA recommends using the MULTIMED model to generate a conservative DAF that can be applied to all suspected contaminants in the landfill leachate. The reported concentrations of each contaminant can be divided by the estimated DAF to determine whether the maximum allowable contaminant concentrations are exceeded at the POC. If the maximum allowable contaminant concentration is exceeded for <u>any</u> contaminant in a landfill, then the proposed design does not meet the EPA performance standard.

The EPA stresses that the purpose of the demonstration for an alternative liner is not to prove that the proposed design is equivalent to the EPA's composite liner design. Instead, the demonstration must show that the alternative design will meet the performance standard contained in §258.40(a)(1). This performance standard states that the concentrations of 24 constituents of concern not exceed the regulatory limits included in §258.40(a)(1). In addition, the HELP and MULTIMED models are not the only means of demonstrating liner adequacy. These models are used frequently because they have been adequately verified and validated with field data, and they require relatively simple, easy-to-obtain inputs, they produce conservative estimates of potential contamination at the POC and they are available free of charge from EPA. Other methods of demonstrating that landfill liners meet the performance standard have been used by landfill owners/operators. Specifically, general infiltration equations (Giroud, et al., 1992; Giroud and Bonaparte, 1989) have been used to estimate infiltration through the landfill liner.

2.0 The HELP Model

This section of the guidance addendum provides insights into selecting model input parameters, interpreting model output, and applying the HELP model to specific landfill design problems. The guidance is based on lessons learned during the application of HELP to the evaluation of a variety of proposed landfill liner designs in many climatological and hydrogeological settings.

2.1 Selection of Model Input Parameters

HELP model inputs fall into three general categories: climate data, landfill layer data, and general simulation data. This guidance is not intended to instruct the user on how to create input files or run the HELP model, but instead to provide insights on how to select appropriate model inputs and on how those model inputs influence model results. Refer to Schroeder, et al. (1994a and 1994b) for a complete description of model use. Also, this guidance will emphasize options for HELP Version 3.

2.1.1 Climate Data

Climate data in the HELP model include **evapotranspiration**, **precipitation**, **temperature**, and **solar radiation** data. These data may be entered by the user or the user may select default values for many U.S. cities that are included in the model. Default values are limited to 5 years of data, but the model can generate simulated precipitation, temperature and solar radiation data for up to 100 years. Evapotranspiration data include **evaporative zone depth**, **maximum leaf area index**, the **start and end of the growing season**, **normal average wind speed**, and **normal average quarterly relative humidity**.

For the evaluation of individual landfill liner designs, the climate data selected should be as representative of the site as possible. If precipitation, temperature or solar radiation data can be obtained for the site itself or for the nearest measurement station, these data should be used in the model. If these data are not available, the user should select default data for the nearest city that has default data in the HELP model or that can be simulated by the HELP model. The user can then adjust the climate data by entering average monthly precipitation and temperature, as well as the latitude for the city where the landfill will be located. For statewide landfill liner designs, the user should select climate data that is representative of the entire state. For states with widely varying precipitation rates, the user may either perform several model runs using precipitation rates that represent the range expected for the state, or choose a high rainfall rate that results in a conservative estimate of infiltration through the landfill.

If a model input parameter is not known and must be estimated, users should select values that result in conservative estimates of infiltration through the landfill liner. For infiltration rates, a conservative estimate is the highest value of the infiltration rate. Therefore, if landfill owners/operators can demonstrate that a proposed design meets the performance standard using the highest possible estimate of an infiltration rate, then it is presumed that the design will meet the performance standard given the actual infiltration rate. The HELP model contains default data for evaporation parameters; however, these data should be modified if site-specific data are available. For example, if the default evaporative zone depth for the nearest city included in the HELP model is 18 inches, but the local agronomy co-op located one mile from the landfill has

measured the evaporative zone depth to be 25 inches, the user should modify the evaporative zone depth in the model scenario to the local agronomy value[1].

The National Oceanic and Atmospheric Administration (NOAA) can provide precipitation, temperature, and solar radiation data. HELP Version 3 is capable of converting NOAA formatted data to HELP formatted data, as well as converting data from Climatedata™ format to HELP format (Schroeder, et al., 1994a).

2.1.2 Landfill Layer Data

Entering data for the design of the landfill itself is the most important consideration in developing a model scenario. The design data used as model input should mimic the proposed design as closely as possible. The HELP model allows the user to enter several layer types. These layer types influence the type of flow that the model computes through that layer. The HELP model characterizes landfill layers according to four layer types: **vertical percolation layers**, **lateral drainage layers**, **barrier soil liners**, and **geomembrane liners**. The HELP model includes some restrictions on the placement of individual design layers and these restrictions are discussed in the following sections.

Figures 1 through 4 illustrate how basic landfill designs are represented in the model. The designs in these figures are illustrative only and are not intended to represent actual landfill designs. In Figure 4, GCL represents geosynthetic clay liners, and FML represents flexible membrane liners. Flexible membrane liners can be used in the HELP model to represent one of any number of geosynthetic landfill liner materials and are referred to a geomembrane liners in HELP Version 3.

2.1.3 General Layer Properties

The model contains default data values for 42 soil types, solid waste, geomembranes, geosynthetics, and other materials. HELP Version 3 also permits the user to define up to 100 additional soil textures that can be saved in a user library. The properties contained in the model for each soil type are **porosity, field capacity, wilting point**, and **hydraulic conductivity**.

The user may define a site-specific soil type either by incorporating field-measured properties of the layer in the landfill design or by modifying a default soil type to reflect measured layer properties. The user should be certain that these changes are realistic for the scenario being modeled. Modifying model inputs is discussed in section 2.1.4 of this guidance.

---

[1] The documentation for HELP Version 3 notes that the evapotranspiration data included in the model for Iowa, Ohio, and Utah are incorrect. Users have the option of entering corrected data into the HELP weather files by hand. Model users may also request a corrected version of the weather data file by contacting:

USAE Waterways Experiment Station
ATTN: Dr. Paul R. Schroeder (EE-A)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

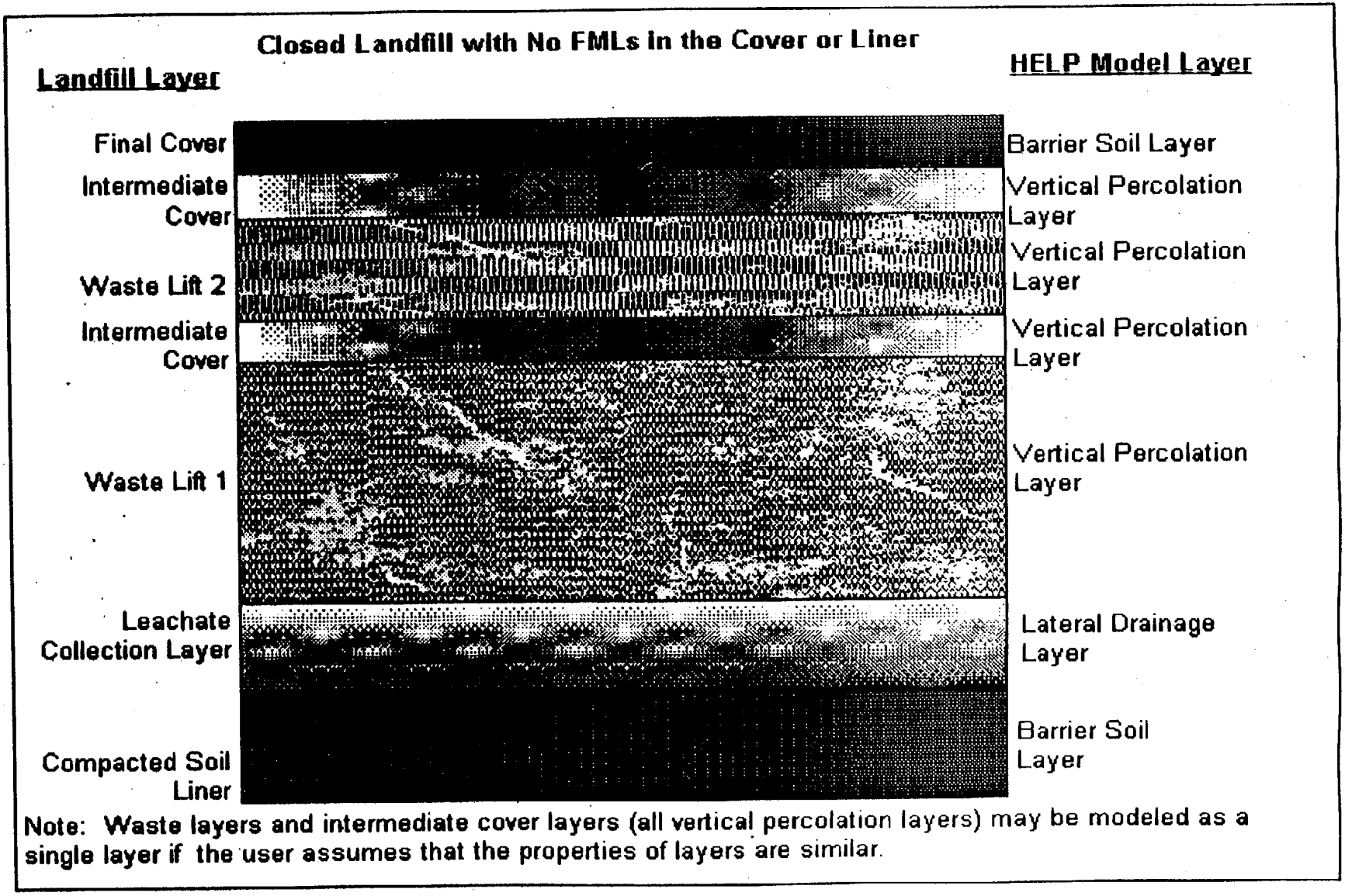

Closed Landfill with No FMLs in the Cover or Liner
Landfill Layer
HELP Model Layer
Final Cover
Barrier Soil Layer
Intermediate Cover
Vertical Percolation Layer
Waste Lift 2
Vertical Percolation Layer
Intermediate Cover
Vertical Percolation Layer
Waste Lift 1
Vertical Percolation Layer
Leachate Collection Layer
Lateral Drainage Layer
Compacted Soil Liner
Barrier Soil Layer
Note: Waste layers and intermediate cover layers (all vertical percolation layers) may be modeled as a single layer if the user assumes that the properties of layers are similar.

Figure 1 **Schematic Cross Section of a Landfill Liner Configuration and the Associated HELP Model Layer Types**

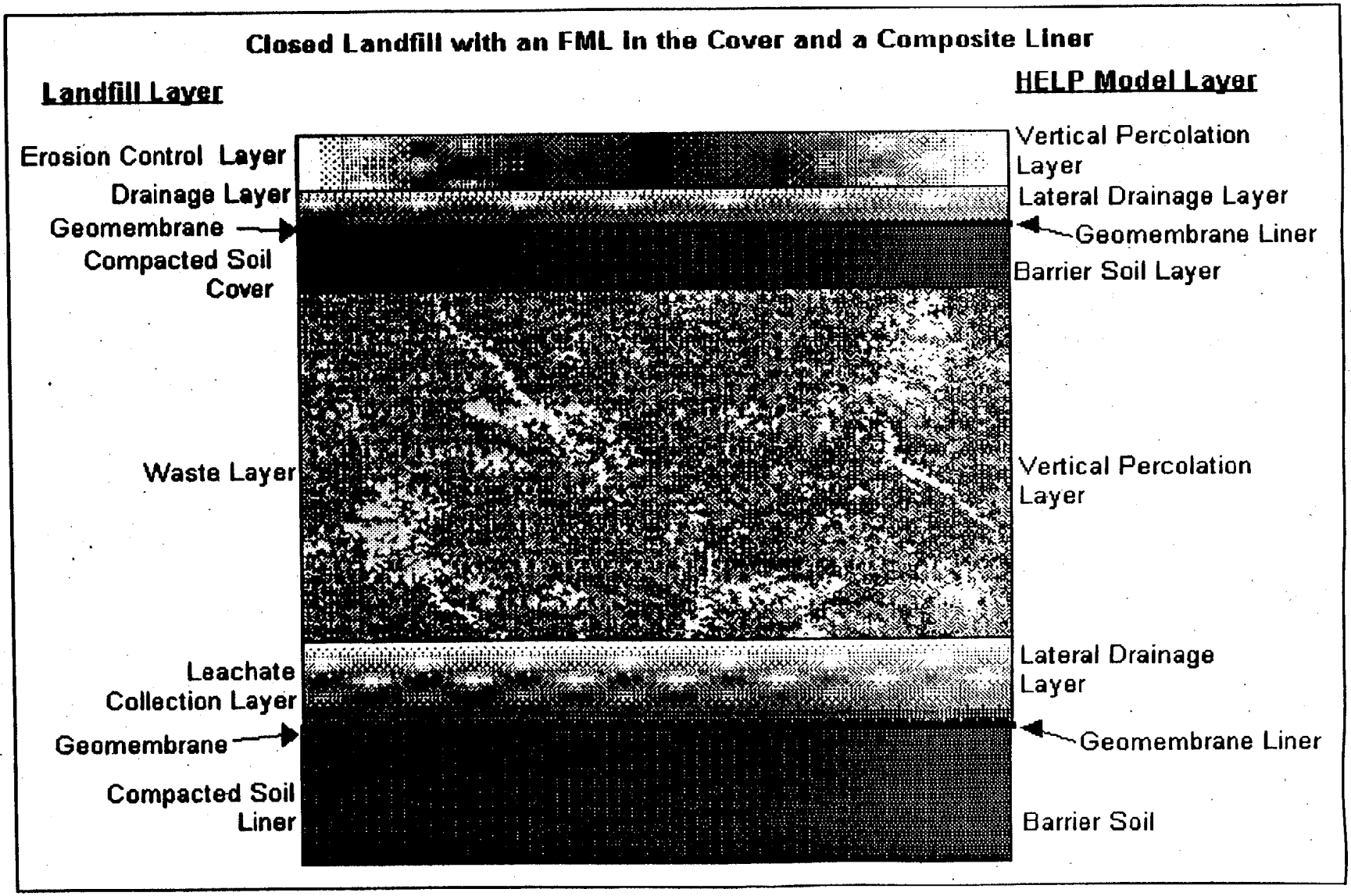


Figure 2 **Schematic Cross Section of a Landfill Liner Configuration and the Associated HELP Model Layer Types**

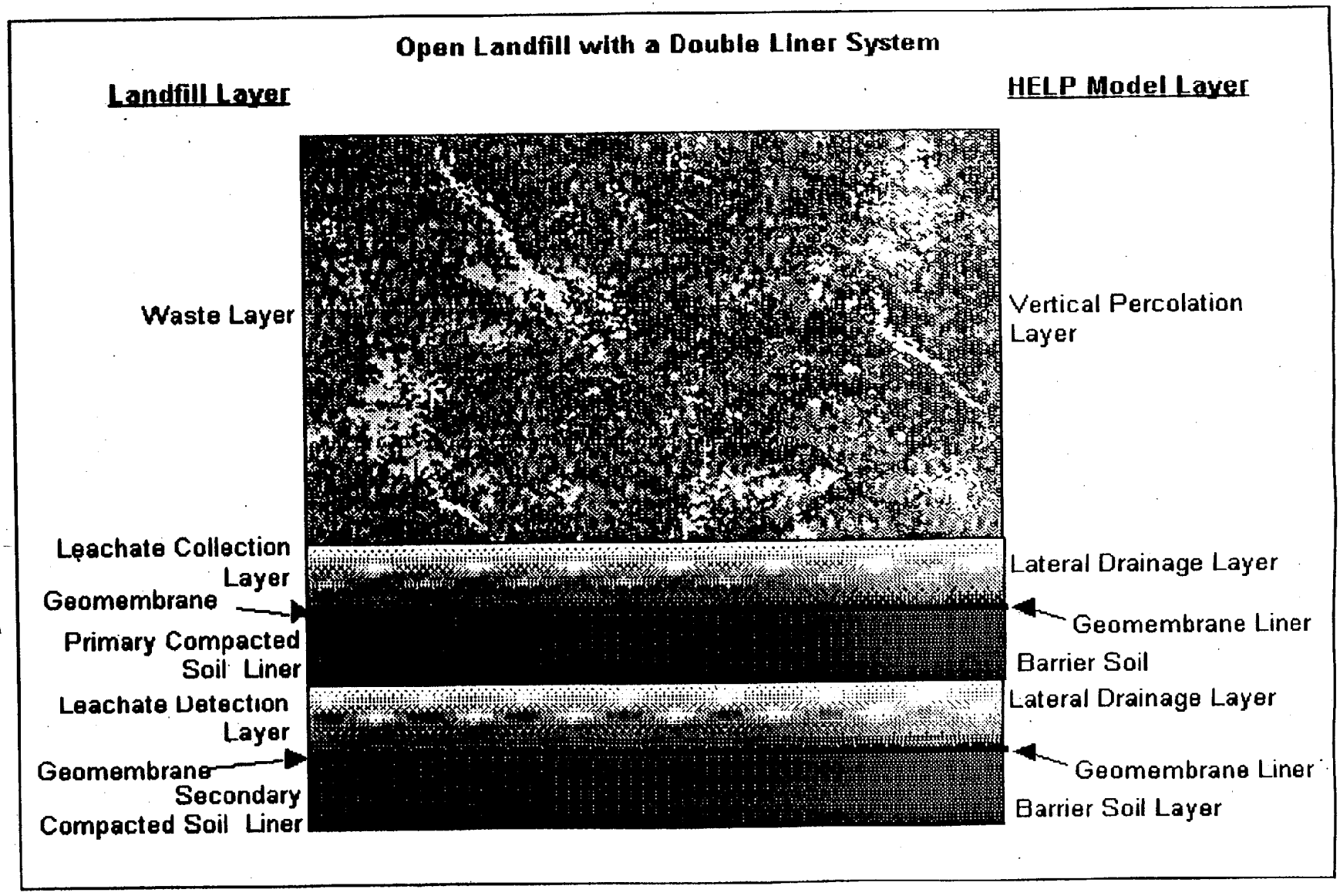


Figure 3 **Schematic Cross Section of a Landfill Liner Configuration and the Associated HELP Model Layer Types**

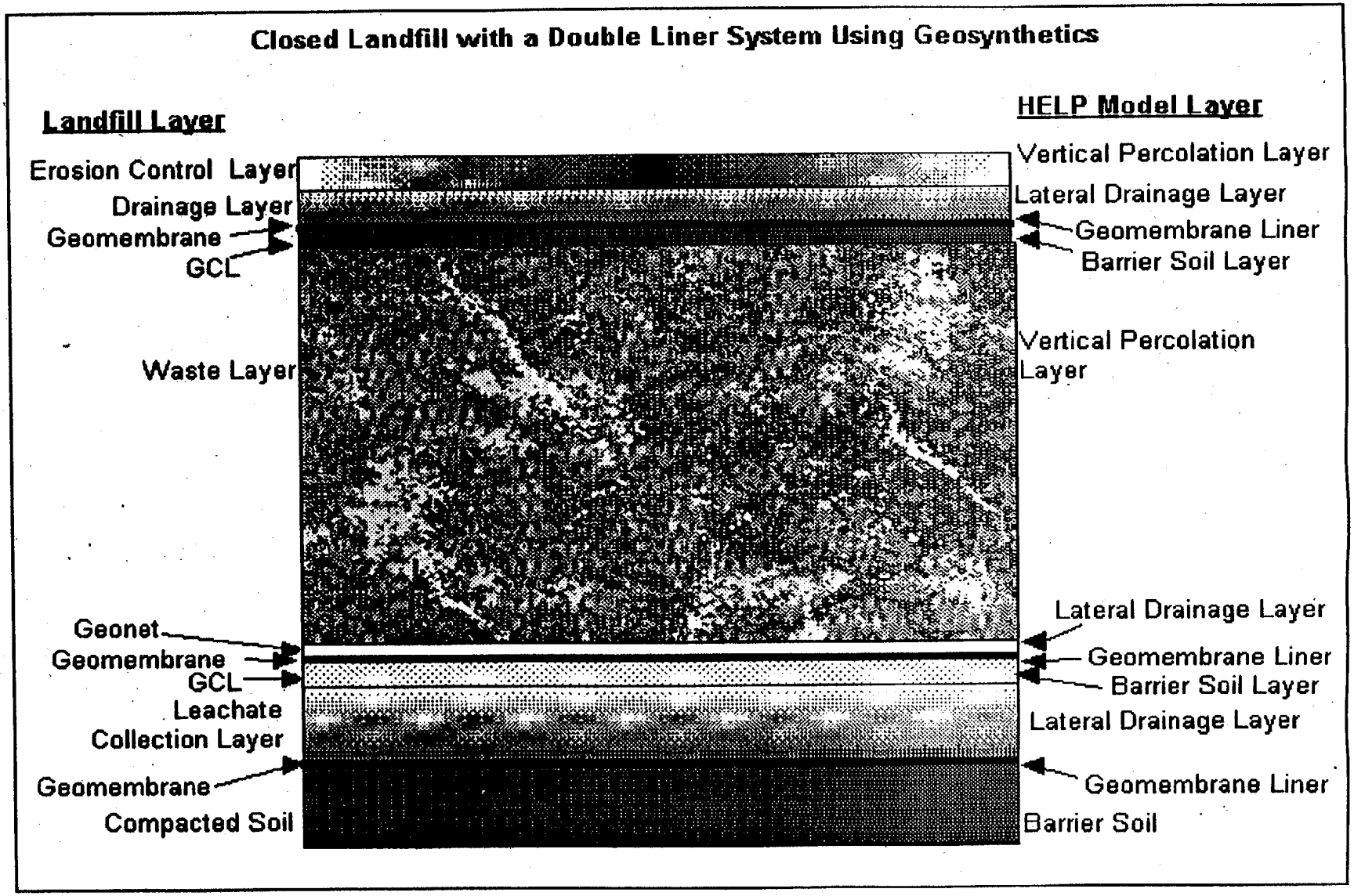


Figure 4 **Schematic Cross Section of a Landfill Liner Configuration and the Associated HELP Model Layer Types**

The HELP model provides the user with the option of specifying the **initial moisture content** for each layer, or allowing the model to estimate this property. Initial moisture content is important because the HELP model does not allow any water to flow through a layer until the soil moisture content of the layer equals or exceeds the soil's field capacity. The initial value for barrier soil layers is set by the model as saturation while all other layers are initialized as a function of the first year's water input and the hydraulic conductivity of the layers above the layer in question. Therefore, the moisture content of a layer may be initialized by the model at a low enough value such that water does not initially flow through that layer. If the user allows the model to initialize moisture content, and flow does not initially occur in some of the modeled layers, the user must be certain to run the model for a long enough period to ensure that moisture equilibrium is reached in each layer. Otherwise, the infiltration predicted from the bottom of the landfill will not be the highest, or most conservative estimate. Methods of modeling design scenarios in which moisture disequilibrium occurs are discussed further in section 2.3.1 of this guidance.

Version 3 of the HELP model contains two modifications to the method used in Version 2 to compute flow through layers. One modification is that the model will account for leachate recirculation. To accomplish this the user must specify the layer from which the leachate is collected and the layer into which the recirculated leachate is placed. The second modification allows subsurface inflow into any of the model layers. If the proposed landfill design contains a leachate recirculation system, or if inflow will occur from a perched water table, or from a water table that is above the bottom of the landfill, these factors should be included in the model scenario. The EPA emphasizes that the layers included in a HELP model scenario should reflect the actual layers of a landfill design as accurately as possible. In addition, all model input values and design specifications should be justified and carefully documented.

Vertical Percolation Layers

A **vertical percolation layer** is any layer through which the primary direction of water movement will be vertical. These layers include final cover erosion control layers, intermediate soil covers, the waste, and any layer not specifically designed to restrict water flow or provide drainage from the landfill. The properties of these layers that will have the greatest influence on the predicted infiltration rate through the layer are the **layer thickness**, the **hydraulic conductivity**, and the **initial soil moisture content**. HELP Version 3 does not allow a vertical percolation layer to be placed directly below a lateral drainage layer and the model assumes that any drainage layers placed below the lowest liner layer are vertical percolation layers.

Lateral Drainage Layers

Lateral drainage layers are layers that contain lateral drainage collection and removal systems. These layers include any layer in the landfill that is designed to remove landfill leachate laterally. Lateral drainage layers often are included in both landfill covers and landfill liners. These layers can include soil layers of high hydraulic conductivity or geosynthetic layers (e.g, geonets). HELP allows for both vertical and horizontal flow in these layers. The layer properties that have the greatest influence on predicted infiltration rates through these layers are the **hydraulic conductivity**, the **layer thickness**, the **lateral drainage slope**, and the **lateral drainage distance**. HELP Version 3 allows users to enter data individually for each drainage

layer. The model does not allow a lateral drainage layer to be placed directly above a vertical drainage layer.

Barrier Soil Layers

Barrier soil layers are soil layers that are designed to restrict vertical flow. Geosynthetic clay liners (GCLs) are represented in model simulations as barrier soil layers (see Figure 4) but geomembrane liners are not. Barrier soil layers are included in the design as a landfill liner layer, and often in the landfill final cover. The layer properties that have the greatest influence on flow through a barrier soil liner include **layer thickness** and **hydraulic conductivity**. The model establishes saturated initial conditions in these layers by setting the soil moisture content to be equal to the layer porosity. Flow through barrier soil layers only occurs vertically in the model. The model places the following restrictions on the location of barrier soil layers in a design:

- barrier soil layers may not underlie another barrier soil layer;
- the top layer may not be a barrier soil layer;
- a geomembrane liner may not be placed between two barrier soil layers; and
- the landfill profile may not contain more than a total of five barrier soil layers and geomembrane liners.

Geomembrane liners

It is not necessary to model **geomembrane liners** as barrier soil layers. Because geomembranes have no intrinsic hydraulic conductivity, flow through geomembranes only occurs as a result of defects in the liners. Data for geomembrane liners are entered separately from barrier soil liner data. The user may specify several properties that control flow through a geomembrane liner including the **pinhole density** (a function of the quality of manufacture of the geomembrane liner), the **installation defect density** (a function of the quality of the liner installation), **liner placement quality** (an estimate of the quality of contact between the geomembrane and the soil liner material), and the **geotextile transmissivity** (if a geotextile is present in the design). The model documentation provides guidance for selecting these values for a particular design. However, if other values can be justified they may be used. For example, one state proposed a design that assumed a much lower liner leakage fraction than that normally assumed by the model. The state officials proposing the design used actual data on leachate volumes collected from existing landfills to justify the use of lower values for liner leakage fraction.

2.1.4 General Simulation Data

Other input data required by the HELP model include the **vegetative cover**, the **landfill area**, the **potential runoff fraction**, the **amount of snow on the land surface at the start of the simulation**, **whether the landfill is open or closed**, and the **Soil Conservation Service (SCS) runoff curve number**. The user must select a vegetative cover type that the model uses to compute the SCS runoff curve number. The input choices are limited to bare ground, poor

grass, fair grass, good grass or excellent grass. This parameter also affects the evaporative zone depth values recommended in the model documentation.

The user should select the **vegetative cover** that most closely resembles the surface vegetation for the landfill being modeled. Open landfills should be modeled as bare ground, and closed landfills should be modeled based on the expected vegetative cover, usually good or excellent grass. The **landfill area** should be site-specific for individual landfills and representative of expected landfill sizes for statewide evaluations. The **potential runoff fraction** represents the fraction of the precipitation that impacts the landfill surface and is expected to run off, rather than infiltrate the landfill. A runoff fraction of 0 is the most conservative value and means that all of the precipitation infiltrates through the landfill. A runoff fraction of 1 indicates that all of the precipitation will run off the landfill and none will infiltrate. Any selection of a value between 0 and 1 should be justified with site-specific or representative data.

The **amount of snow on the land surface at the start of the simulation** should be 0 unless some alternative amount can be justified. Landfills should be modeled as open for as long as the landfill is uncovered. Users have the option of conducting multiple model runs, one representing the landfill in open conditions, and one representing the landfill in closed conditions, to model the long term variations in infiltration. Conducting multiple model runs to more accurately simulate landfill operating procedures is discussed in section 2.3.1 of this guidance.

The SCS runoff curve number method is used to compute the amount of runoff based on a curve that relates runoff to precipitation and retention (the difference between rainfall and runoff). In HELP Version 3, the user has the option to enter a **runoff curve number** that will be modified by the model to account for slope angle and slope length. The user may instead allow the model to estimate a runoff curve number that also accounts for slope angle and slope length. HELP Version 3 also has an option that allows the user to enter a curve number and not have it modified in any way.

2.1.5 Modifying Model Inputs

Default HELP model inputs should be modified whenever the default values do not accurately represent site-specific conditions for individual landfills, or when the default values do not represent reasonable statewide conditions. HELP Version 3 allows the user to create, save, and modify individual soil and climate input files as necessary. Input screens also are presented in a spreadsheet-like format that allows the user to see all of the information for a particular data entry function on one or two screens, rather than answering a series of questions, as was done in earlier versions of HELP. Changes can be made to input parameters simply by retrieving an existing input file, making the necessary modifications, and saving the file under its existing name or under a new name. Unlike earlier versions of HELP, the user interface in version 3 is convenient, so there is no need for a user to modify input files using an ASCII editor.

2.2 Interpreting Model Output

The HELP model output is provided in several sections; **a listing of the model input parameters, average monthly values, average annual totals, peak daily values,** and **final water storage**. The data reported in each of these sections not only allows the user to determine the final infiltration rate from the bottom of the landfill, but also allows the user to evaluate the

reasonableness of the HELP results. The user should review more than the final infiltration rates to determine if those predicted rates are appropriate and reasonable for use in the MULTIMED model, as discussed in sections 2.2.1 through 2.2.4 of this guidance. HELP Version 3 allows the user to perform calculations with either English or metric units.

2.2.1 Average Monthly Output Values

Average monthly values and their standard deviations are provided for **precipitation, runoff, evapotranspiration, lateral drainage** from each layer for which lateral drainage is allowed, and **percolation** from all vertical percolation layers. The EPA uses this data only to determine whether the precipitation, runoff, and evapotranspiration estimates are reasonable for the alternative landfill liner design that is being evaluated. The EPA compares the values entered for precipitation and evapotranspiration to monthly average values available from the National Climatic Data Center for weather stations near the landfill for site-specific demonstrations, or to statewide values for statewide demonstrations. Estimates of runoff are evaluated to determine their reasonableness given the general climate for the state where the landfill is located.

2.2.2 Average Annual Output Values

The average annual totals and standard deviations should be reviewed with more scrutiny than average monthly values because the estimate of **infiltration from the bottom landfill layer** is the estimate that is used as input to the MULTIMED model. The estimates of average annual **lateral drainage** from each drainage layer are used to determine the effectiveness of the design drainage layers and to determine whether flow and moisture equilibrium have been reached by the model. If no flow is predicted in a lateral drainage layer, it is likely that flow equilibrium has not been reached during the simulation. This can happen if the model is run for five years or less. Methods for running the model for a longer period of time are discussed in section 2.3.1 of this guidance.

The **change in water storage** also is an indication of whether moisture and flow equilibrium has been reached during the simulation. A large positive value indicates that water is still accumulating in the landfill profile. A negative number indicates that water is being lost from the landfill profile. Negative numbers occur most often in arid areas, where evapotranspiration is significant. **The EPA recommends running a model simulation at least until moisture equilibrium is reached. The number of years run in the HELP model are not necessarily related to the proposed life of the landfill.** The purpose of conducting the HELP modeling is to predict the worst-case (i.e. maximum) infiltration that is likely to occur for a specific landfill liner design. One very wet year, or even one large precipitation event, may cause landfill layers to become saturated and produce peak flow on a time scale very different from that predicted by the HELP model. In some situations, moisture equilibrium may never be predicted by the HELP model (as in cases where evapotranspiration might be excessive). In these cases, the worst-case situation is when the model predicts that flow is occurring in each model layer. However, once the model does predict that moisture equilibrium is reached, then a model user may run the model for lengths of time equivalent to each phase of landfill development. In this way, changes in flow during various landfill phases may be modeled.

2.2.3 Peak Daily Output Values

The only parameter of concern to the EPA in the peak daily values section of the output is the **peak head predicted on the top liner layer**. This is often a design standard for landfills. For example, some states require that the head on the liner is not to exceed one foot. The HELP model can be used to verify that the design standard is met.

2.2.4 Final Water Storage

Data on **final water storage** at the end of the model run can be used to support the determination that moisture and flow equilibrium have been reached. If the final water storage does not change as the length of the model run increases, then equilibrium has been reached. If longer time periods are simulated using multiple sequential model runs, the final water storage values should be used as input for the initial moisture content for each layer in subsequent model runs.

2.2.5 HELP Output Used as MULTIMED Input

Two HELP model output values are used as MULTIMED input: **infiltration from the bottom of the landfill** (the HELP model average annual percolation from the lowest landfill layer), and **precipitation**. The user may select either net or total precipitation as MULTIMED input. The effects of net versus total precipitation are discussed later in this guidance.

2.3 HELP Model Configurations for Specific Landfill Configurations

The EPA has evaluated numerous proposed landfill liner designs in a variety of climatologic and hydrogeologic regimes. Based on this experience, the EPA has determined that certain landfill liner design elements or environmental inputs require careful consideration of the model configuration used to evaluate a landfill liner design. This section discusses recommended model configurations that address both minor limitations of the HELP model and specific design elements or environmental inputs. Specifically, this section discusses modeling approaches for:

- Modeling more than 5 years of landfill infiltration;
- Modeling synthetic liners that are not part of composite liners;
- Modeling the influence of landfill geometry;
- Modeling geosynthetic clay liners (GCLs); and
- Modeling landfill covers.

2.3.1 Modeling More Than 5 Years of Landfill Infiltration

The default length of time for a single HELP model run is a maximum of 5 years using actual rainfall and 100 years using simulated rainfall. Often, 5 years is not long enough for the model to reach moisture equilibrium. In drier climates, even 20 or more years may not be enough to reach equilibrium. While the user has the option of entering rainfall and temperature data manually rather than using the default data, this information may be difficult to obtain for the number of years needed for a model configuration.

One solution to this limitation is to run the model with default rainfall data several times in sequence. That is, leave all design and climate input parameters the same, but use the final water storage, in volume per volume, from each layer in the first model run for the initial moisture content for each layer in the second model run. In this manner, the user may simulate as many years as are necessary to reach moisture equilibrium conditions in the model simulation.

Moisture disequilibrium can be caused by the HELP model initializing soil moisture for the modeled landfill at low values due to low rainfall, high evapotranspiration, or low hydraulic conductivity of the layer above the design layer not in equilibrium. To determine whether this has occurred in a model run, the user may plot a time series of the infiltration from the bottom of the landfill. If the initial moisture content results in moisture disequilibrium (moisture accumulating in the landfill), then the infiltration from the bottom of the landfill will be low initially, then increase to a constant value. Figure 5 illustrates this condition. If model results predict this trend in infiltration from the bottom of the landfill, the user should be certain to run the model simulation long enough to achieve a constant infiltration rate. This constant rate should then be used as the infiltration rate to the MULTIMED model.

In some cases, the initial moisture disequilibrium can be explained by changes in precipitation early in the simulation. If the low initial soil moisture of the modeled layers does reflect lower precipitation rates, then the user should accept the results and run the model until moisture equilibrium is reached. However, if changes in precipitation during the early part of the simulation cannot explain the low soil moisture, then the initial moisture content estimated by the HELP model for some of the landfill layers may be too low. The model user may then manually increase the initial soil moisture content of the layer where water is accumulating in the landfill profile until the infiltration is relatively constant from the bottom of the landfill. This condition is shown in Figure 6. The layer with low initial soil moisture is most often the waste layer, but changes in the final moisture content for each design layer reported in the HELP output will indicate all layers where moisture is accumulating.

The movement of moisture in the landfill can be simulated over its life span by using multiple sequential model runs. That is, the duration of the active life of a landfill can be simulated with the landfill in open condition, then the post-closure period can be simulated with the model in closed condition. Individual landfill lifts can be simulated in this manner as well. This approach requires adding new layers (as dictated by the specific landfill design) to each sequential model run, as well as entering the final water storage for existing layers as the initial moisture content of multiple model runs. This approach more accurately simulates the influence of adding new layers to a landfill over time on the water balance for the entire design.

While HELP Version 3 contains only 5 years of default rainfall data, the user is provided with methods to enter measured rainfall data for any number of years for which data are available. In addition, the model allows the user to simulate up to 100 years of rainfall and temperatures, so that 100 years may be simulated in a single model run. The user may also use simulated rainfall for time periods representing different phases of landfill development to model the expected life span of the landfill, if moisture equilibrium is reached in each of the model runs.

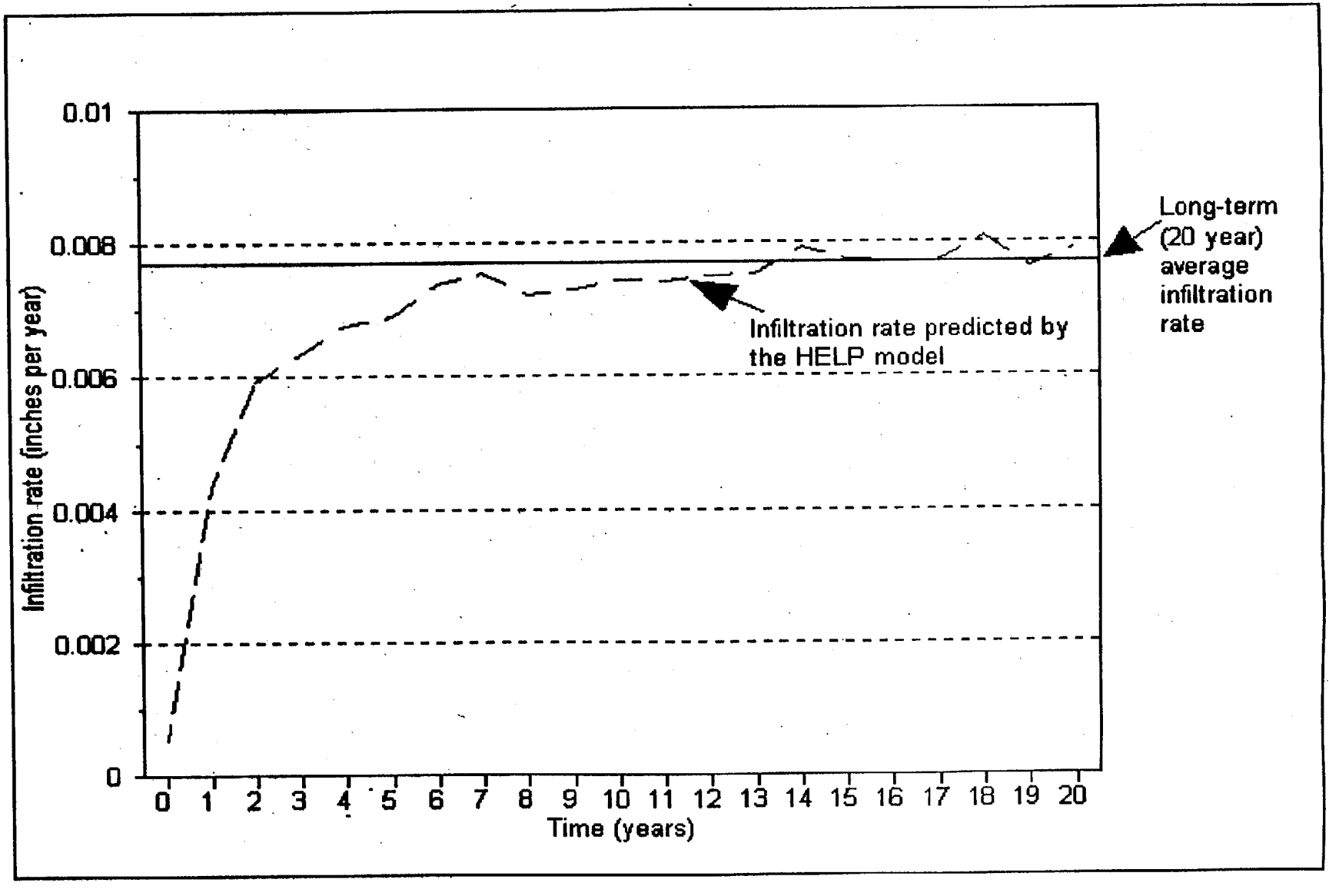

0.01
0.008
0.006
0.004
0.002
0
Infiltration rate (inches per year)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time (years)
Long-term (20 year) average infiltration rate
Infiltration rate predicted by the HELP model

Figure 5 Example of Infiltration from a Landfill with Low Initial Soil Moisture Content

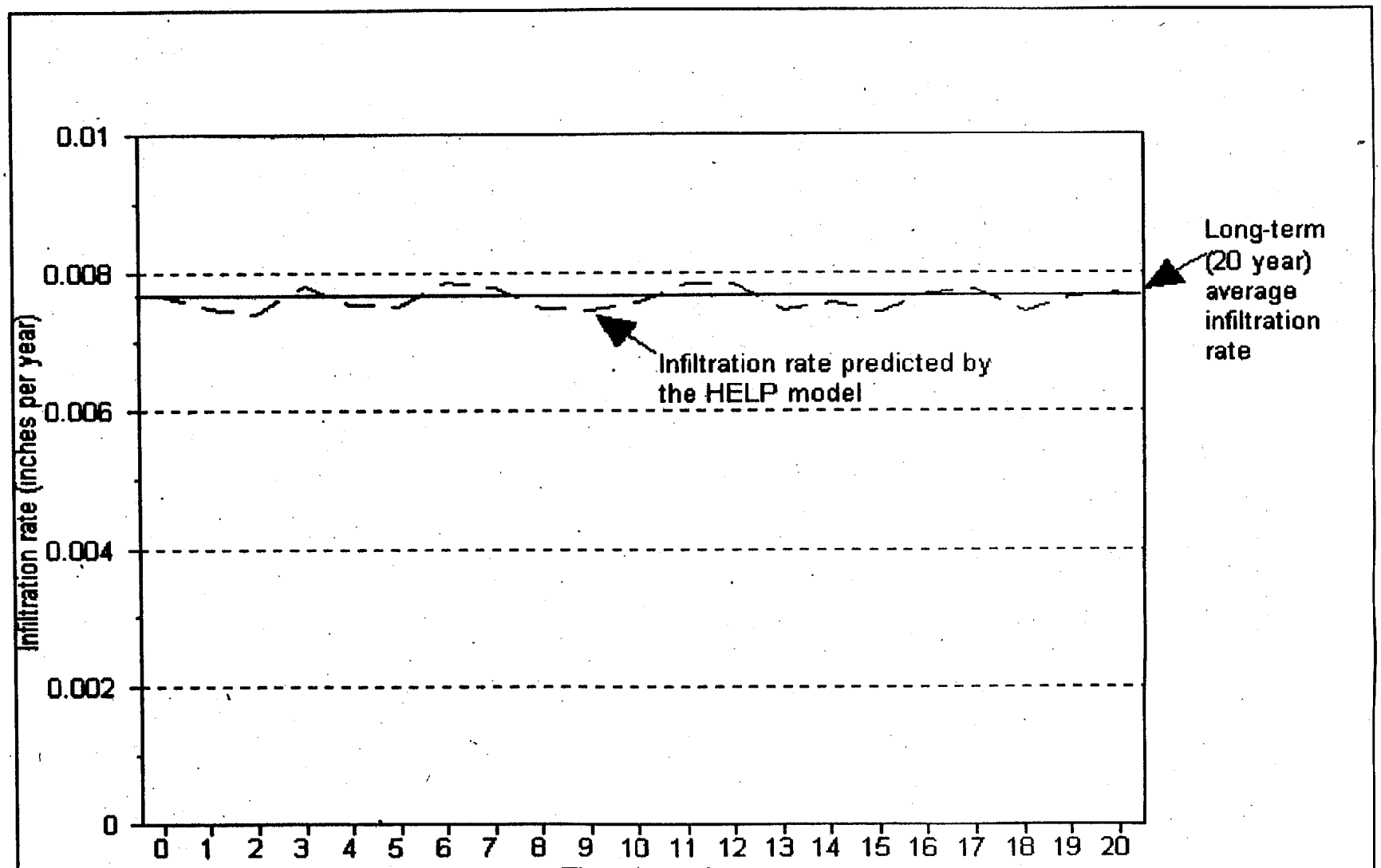

0.01
0.008
0.006
0.004
0.002
0
Infiltration rate (inches per year)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time (years)
Long-term (20 year) average infiltration rate
Infiltration rate predicted by the HELP model

Figure 6 **Example of Infiltration from a Landfill with Appropriate Initial Soil Moisture Content**

2.3.2 Modeling Synthetic Liners That Are Not Part of Composite Liners

In HELP Version 2, geosynthetic liners could be modeled only if they were part of a composite liner, so designs that contained geosynthetic liners that ware not part of a composite liner were difficult to evaluate. The HELP Version 3 revisions include provisions for geosynthetic liners as layers that are distinct from adjacent soil layers. The model mathematics are now capable of calculating flow for any configuration of adjacent landfill layers. In Version 3, the model user enters each layer of the proposed landfill design, and the model calculates infiltration based on that configuration.

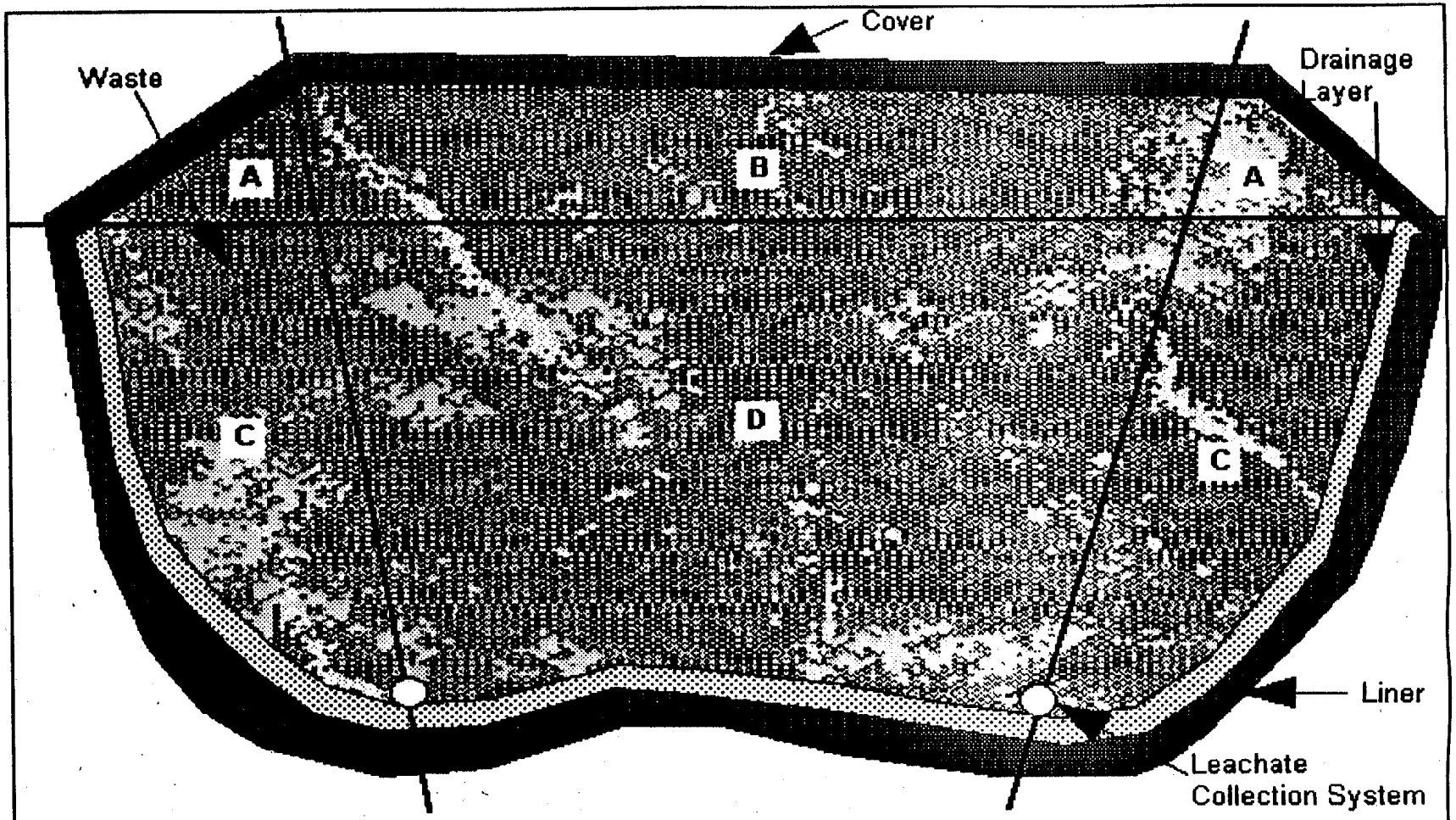
In order to estimate the moisture flow through a geosynthetic liner, model users must estimate the frequency of defects expected during installation. The user must estimate a pinhole defect density, an installation defect density, and the liner placement quality. All of these factors are a function of installation quality except pinhole defect density which is a manufacturing characteristic. The model documentation provides guidance for selecting values for each of these parameters. The user should select these parameters to be conservative, that is, to err on the side of predicting higher infiltration rates. The model user may select values for these parameters that are different from the HELP model recommendations if other values are justified. For example, the installation defect density can be back-calculated from measured volumes of leachate collected above a geosynthetic liner. If a State or an owner/operator can demonstrate that very high installation quality has been achieved in other liner installations, a lower defect density may be used in the HELP model.

2.3.3 Modeling the Influence of Landfill Geometry

Landfill geometry can have a significant effect on the infiltration rate predicted by HELP Version 3. Runon and runoff at the landfill surface can increase or decrease infiltration rates, respectively. Leachate tends to migrate more quickly along landfill side slopes, increasing the head on the bottom liner, and thereby increasing the infiltration through the liner. By conducting HELP model runs that represent only portions of a landfill design, the model user can account for the variations in flow caused by landfill geometry. The total infiltration will be the sum of the infiltration amounts predicted for each landfill segment. The model documentation contains guidance on the proper application of the HELP model for various landfill geometries. Model users should have knowledge of the influence of landfill slopes on the infiltration through a landfill liner (U.S. EPA, 1990).

This approach of evaluating sections of landfill designs does not work well for evaluating a statewide design because the approach is very dependent on the site-specific geometry. An evaluation using geometry that is expected to be representative of the conditions for the state is the appropriate technique.

The most important variables in predicting the effectiveness of lateral drainage layers are lateral drainage slopes and lateral drainage slope lengths. Therefore, the model user should be certain that the drainage layer geometry included in the model scenario accurately represents the proposed design. If design requirements will be different for different portions of the proposed landfill, the landfill should be modeled in segments, and the total infiltration calculated as the sum of the infiltration from each segment. Figure 7 shows the possible division of a landfill into sections that can be modeled as separate segments. For example, the sections marked A in the figure may be modeled as a single waste layer with a sloped cover and section B would be



Note: Solid black lines show the areas of a landfill that might be modeled separately. Each area that may be modeled is labeled with a letter. See Section 2.3.3 for a discussion of how to determine whether each area should be modeled individually. Runoff, runon, and infiltration from adjacent areas must be included in the modeling configuration for each area.

Figure 7 Schematic Landfill Cross Section Illustrating Options for Modeling Landfill Geometry

modeled as a single waste layer with a horizontal cover. Runoff from section B should be included as runon for section A. Infiltration from section A would be used as input to section C, and infiltration from section B would be used as input for section D. Finally, the infiltration from the bottom of the landfill would be the total infiltration from sections C and D. Users should always justify why certain segments are or are not modeled separately.

2.3.4 Modeling Geosynthetic Clay Liners (GCLs)

Geosynthetic clay liners (GCLs) are relatively new landfill liner technologies that have been proposed as part of landfill liners for several designs that the EPA has evaluated. GCLs consist of thin (1 inch or less), very low hydraulic conductivity (1×10^{-9} cm/s or less), clay mats that can be used in place of compacted clay layers. The clay mat is often attached to, or sandwiched between geotextiles. HELP Version 3 contains default properties for GCL materials. GCLs should be entered into the model as barrier soil liners. Any other materials installed with the GCL (e.g, a geonet for drainage) should be entered as a separate layer. Strict adherance to field QA/QC procedures for GCL installations is essential to ensure the integrity of a GCL (U.S. EPA, 1994). These clays are very thin and can be damaged during installation. They also must be installed and covered while they are moist, because if they dry out, desiccation cracks will form and the actual hydraulic conductivity of the layer will be much higher than intended. Finally, GCLs generally are not stable on steep slopes (greater than about 3 percent, in most cases) and may slip, reducing their effectiveness in restricting vertical flow. The HELP model does not specifically account for the expected QA/QC of a GCL installation. However, the possibility of the formation of desiccation cracks may be evaluated by increasing the saturated hydraulic conductivity of the GCL. Users should provide justification for any estimates of changes in hydraulic conductivity that may result from GCL installations.

2.3.5 Modeling Landfill Covers

The intent and effect of including cover materials in a landfill design is to either limit erosion (for intermediate soil cover) or to limit erosion and infiltration into the landfill (for final covers). Regulations in 40 CFR Part 258 state that the hydraulic conductivity of final cover materials shall not be greater than the hydraulic conductivity of liner materials to prevent the accumulation of leachate in a landfill that results in a "bathtub effect." Intermediate covers generally do not restrict flow into a landfill to the same extent that final covers do.

The effect of final covers on HELP model results is that total predicted infiltration from the bottom of the landfill is reduced, but that it also takes longer for the model to reach flow and moisture equilibrium. **Therefore, model scenarios that include a final cover need to be run for a longer period to predict potential worst-case infiltration from the bottom of the landfill.**

2.4 Alternative Methods for Calculating Liner Infiltration Rates

The most common alternative method for estimating infiltration through proposed liner designs is based on a set of equations developed by Giroud and Bonaparte (1989) and Giroud et al. (1992). These equations estimate infiltration through a geomembrane liner based on:

- an assumed liner defect size and density;
- an assumed quality of contact between the geomembrane and the underlying soil;
- an assumed head on the geomembrane liner; and
- the hydraulic conductivity of the soil underlying the geomembrane liner.

These equations are the basis for the calculations used in Version 3 of the HELP model. Owners/operators have used these equations in the past to overcome some of the limitations of HELP Version 2. Owners/operators may also use these equations if they do not have access to the HELP model.

Any estimates of defect size, defect density, and quality of liner contact should be justified for the specific liner design being modeled. The HELP model provides some guidance for selecting these parameters. The maximum allowable head on the liner is usually a design standard. Giroud and Bonaparte (1989) and Giroud et al. (1992) have developed two sets of model equations; one predicts infiltration assuming good contact between the geomembrane and the underlying soil, and the other predicts infiltration assuming poor contact between the geomembrane and the underlying soil. Assuming poor contact between the geomembrane and the underlying soil predicts a higher infiltration rate, and therefore is more conservative.

3.0 The MULTIMED Model

The MULTIMED model is an analytical ground-water flow and transport model that can be used to estimate the effects of dilution and attenuation on contaminant concentration during transport from a landfill to a downgradient POC. The model includes modules for estimating contaminant transport in both the unsaturated and saturated zones. A user interface (PREMED) is distributed with the model to assist the user with building input data sets. This section provides an overview of the application of MULTIMED to the evaluation of proposed liner systems for solid waste landfills.

3.1 Existing Guidance on the Use of MULTIMED

In addition to the document that describes the model theory of MULTIMED (Salhotra, et al., 1990) and the application manual for MULTIMED (Sharp-Hansen, et al., 1990), the EPA provides a tutorial (U.S. EPA, 1992) and a User Manual Supplement (Allison, 1993) as guidance for the use of MULTIMED to review Subtitle D landfill designs. The tutorial is intended to provide the user with step by step instructions on how to determine input values and run both the HELP and MULTIMED models. The User Manual Supplement is intended to provide a brief guide to MULTIMED, explain its role in evaluating landfill designs, and provide examples of its use.

Since the development of these documents, the EPA and the state regulatory authorities have encountered a number of issues related to the use of MULTIMED. This section describes each of these issues and provides guidance for addressing each issue to ensure the effective and accurate application of the MULTIMED model.

3.2 Questions Regarding MULTIMED Model Input for Evaluating Landfill Permit Applications

Several recurring questions with respect to the use of MULTIMED have arisen during the evaluation of proposed liner designs for site-specific and statewide application in State/Tribal landfill programs. These questions generally are related to the following issues:

- the use of the steady-state vs. the finite-source assumption;
- including the unsaturated zone in the MULTIMED model analyses;
- including the effects of chemical decay, biodegradation, or sorption processes;
- using MULTIMED to model low hydraulic conductivity aquifers;
- whether or not to use Monte Carlo simulations; and
- the use of total vs. net precipitation.

Each of these questions is addressed in the following sections; insights gained and lessons learned during the evaluation of petitions for alternative liners and the evaluation of statewide liner designs are discussed.

3.2.1 Steady-State Source vs. Finite-Source Assumption

To run MULTIMED, the user must determine if the source of contaminants leaching from a landfill can be assumed to be infinite (steady-state source term) or finite (unsteady-state or transient source term). The selection of the source term is described in the following sections.

Use of the Steady-State Assumption

The steady-state assumption is the simplest and most conservative approach for evaluating landfill designs, because it assumes that the source of contaminants is infinite. In other words, the landfill will leach contaminants at a constant concentration, and the contaminant concentrations at the POC will achieve a steady-state. The initial landfill design evaluations usually assume a steady-state source term because it is more conservative and requires less data. If the design passes using this conservative assumption, the design will definitely pass using the finite-source assumption.

The steady-state modeling approach used by MULTIMED assumes that the source of a contaminant (landfill leachate) is continuous and has a fixed concentration that does not change as a function of time. This results in a contaminant concentration in a downgradient receptor well at the POC that, while it is less than the concentration in the leachate (as a result of dilution and dispersion), it is continuous and fixed at a given magnitude. The concentration at the POC is a fraction of the leachate concentration. The reciprocal of that fraction is the DAF. The steady-state approach is conservative because it assumes that there is an infinite source of leachate. Therefore, if the liner design meets the performance standard using this conservative steady-state approach, the performance standard at the POC should be readily attained using a finite source of leachate. The steady-state assumption also is the simplest approach to use as it does not require an estimation of the duration of the source of contaminants leaching from the landfill.

Use of the Finite-Source Assumption

MULTIMED provides reviewers of landfill liner designs with the option to evaluate proposed designs assuming a finite source of contaminants (referred to as the "Transient case" in PREMED and MULTIMED). However, the Agency recommends using the finite-source approach only if sufficient data are available to justify the assumption that leachate will infiltrate from the landfill for a limited period of time. Use of the finite-source approach requires an estimate of the duration of time (in years) during which a specific contaminant will leach from a landfill. The duration of leachate generation, in turn, is based on the mass of contaminant in the landfill. The contaminant mass is calculated using estimates of landfill capacity, the concentration of contaminants in the waste, and other parameters, as discussed below. The objective of the finite-source approach is to determine if contaminant leaching from a landfill for a finite period of time will result in concentrations exceeding the performance standard at the POC.

In finite-source modeling, the concentration of a contaminant at the POC is a function of the duration of the leachate leakage pulse or "pulse duration". The **pulse duration** in MULTIMED represents a "pulse" of a contaminant being released from the landfill for a finite period of time, after which, no more contaminant leaches from the landfill. This contaminant pulse migrates downgradient from the landfill to the POC. This method contrasts with the steady-state approach (discussed above) which assumes that the contaminant continuously leaches from the landfill and eventually reaches a constant (steady-state) concentration at the POC.

For example, a pulse duration of 10 years implies that the contaminant will leach from the landfill at a specific concentration for 10 years only, and then migrate to the POC. The migration of the contaminant can be illustrated by plotting the concentration of the contaminant at the POC as a function of time (Figure 8). At some point in time, the concentration of the contaminant at the POC will increase to a maximum concentration and then decrease as the finite contaminant mass migrates past the POC. The maximum concentration reached at the POC is used to determine if contaminant concentrations will exceed the performance standard. If the pulse duration is set to a long enough period of time, the contaminant concentration at the POC will increase to the point where it is equivalent to the contaminant concentration predicted using the steady-state source assumption (Figure 8). It should be noted that Figure 8 only provides examples of finite contaminant sources and is not intended to specifically represent changes in POC concentrations for an actual landfill.

The pulse duration is a function of the **mass of the contaminant in the landfill**, the **leaching rate**, and the **concentration of contaminant in leachate**. The mass of contaminant in the landfill, in turn, is based on the **density of waste in the landfill**, the **fraction of this waste that contains the contaminant of concern**, and **the concentration of the contaminant** in that fraction of the waste. However, estimating these parameters can be difficult and may be subject to a high degree of uncertainty. The method for computing the mass of a constituent in a landfill and pulse duration is described in detail in Allison (1993) and is summarized here.

The pulse duration, T_p, is calculated using the following equation:

$$T_p = \frac{M_a}{q\, C_l\, 1000}$$

where:

M_a = mass of the constituent in the landfill per square meter of surface area (mg/m^2)
q = infiltration rate (m/yr)
C_l = concentration of the constituent in leachate, (mg/l):

The mass of the constituent (M_a) is computed with the following equation:

$$M_a = C_w\, d\, P_{bw}\, F$$

where:

C_w = concentration of the contaminant in the waste (mg/kg)
d = depth of the landfill (m),
P_{bw} = density of the waste stream (kg/m^3)
F = the volume fraction (unitless) of landfill occupied by the waste stream

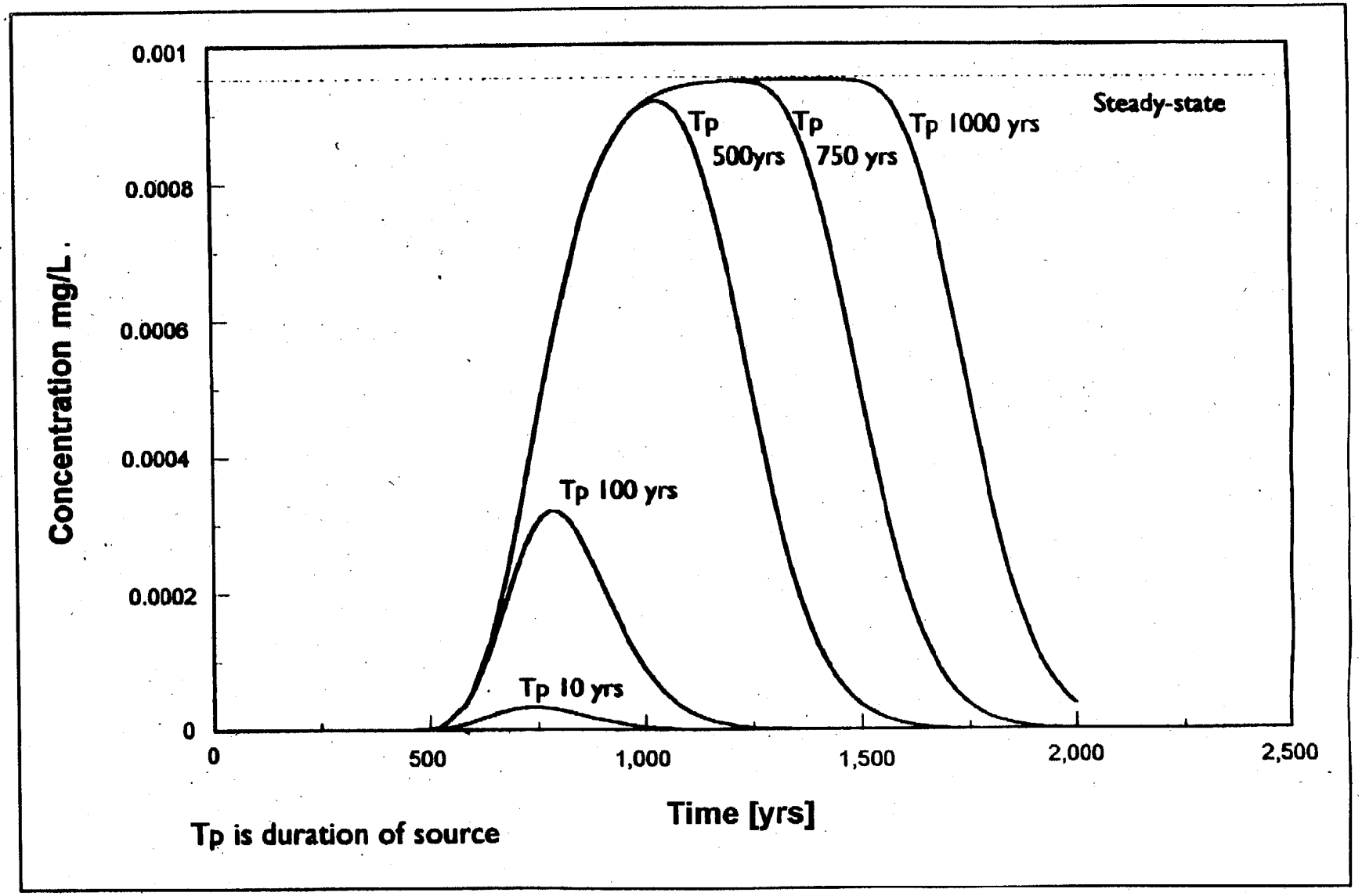


Figure 8 **Finite-Source Model Response vs. Steady-State Model Response**

The user implements the finite-source approach in MULTIMED by computing the pulse duration (T_p) using the equations described above. The user selects the **Transient case** and sets **duration of pulse** in PREMED to the value computed for T_p. The user then determines the maximum concentration at the POC (listed in the MULTIMED output) to compute the DAF, the same way the concentration at the POC is used to compute the DAF for the steady-state approach. **Because of the uncertainty in estimating these parameters, the Agency recommends that the finite-source assumption only be used when sufficient data are available to compute the pulse duration.**

3.2.2 Modeling the Unsaturated Zone

The MULTIMED model requires that the user specify if the unsaturated zone will be included in the modeling effort. For some modeling scenarios, including the unsaturated zone will have no effect on the results. Including the unsaturated zone in the modeling analysis will have no effect if the steady-state assumption is used and the simulation does not include contaminant decay. However, the unsaturated zone should be included if the simulation assumes a finite-source term or if the simulation includes contaminant decay. The effect of including the unsaturated zone for the finite-source scenario would be to increase the amount of time required for a contaminant to travel from the base of the landfill to the POC. The effect of including the unsaturated zone and accounting for contaminant degradation would be to decrease the contaminant concentration as well as increase the amount of time required for the contaminant to reach the POC.

The unsaturated zone flow model requires values for the following parameters: **residual water saturation, and alpha and beta van Genuchten water retention coefficients**. These parameters should be set to values that are representative of the type of soil material expected to be encountered in the unsaturated zone. Values for these parameters and guidance for selecting appropriate values are provided in the MULTIMED documentation (Sharp-Hansen et al., 1990).

3.2.3 Chemical Decay/Biodegradation/Sorption Coefficients

In addition to contaminant dispersion, the MULTIMED model can incorporate chemical decay, biodegradation, and sorption process that may decrease estimated concentrations of contaminants in the subsurface. MULTIMED can account for sorption to soil particles and chemical decay and biodegradation in the form of a first-order decay process.

Input Parameters Related to Sorption/Decay Processes that May Influence Model Results

Including sorption and decay in MULTIMED analyses requires values for intermediate parameters that are used to compute the effect of these processes on contaminant concentrations. The parameters related to sorption that influence model results for organic constituents are the **normalized distribution coefficient**, which estimates the affinity of the chemical for organic carbon, and the **fraction organic carbon**. The chemical decay rate is computed by the model from ambient **pH**, the **acid**, **neutral**, and **base hydrolysis rates** for the constituent being modeled, and from the **partition coefficient**. The biological decay rate is calculated using a single, **first order decay coefficient** that is estimated by the user.

It is appropriate to include sorption and decay processes only when sufficient data are available to justify their inclusion. Justification should include evidence that sufficient data are available for each parameter (preferably field data) and the data values are known with a high degree of certainty. For example, actual biological decay rates are subject to a high degree of uncertainty and may vary as a function of the type of constituent and site-specific hydrogeologic characteristics. If the data are subject to a high degree of uncertainty, justification should be provided to show that the data values are conservative.

Conservative Assumptions Related to Including Decay Processes/Sorption

MULTIMED makes a distinction between chemical decay, as a result of hydrolysis, and biological decay. This distinction is appropriate because there is a difference in the degree of uncertainty associated with these two processes. Chemical decay, or hydrolysis, is well understood and can be included in the modeling with relative certainty. Biodegradation is not as well understood, and cannot usually be included with as much certainty. To incorporate biodegradation into the model, the user is required to summarize the decay process into a single first-order constant.

The partition coefficient used to approximate chemical decay for organic constituents is calculated from the **normalized distribution coefficient** which is a constituent-specific parameter available from published chemical databases, and the **fraction of organic carbon** (f_{oc}) in the aquifer being simulated. The fraction of organic carbon should be based on field measurements or can be based on the **percent organic matter** (f_{om}) using a relationship developed by Einfeld et al. (1982):

$$f_{oc} = f_{om}/172.4$$

In sorption processes, the relationship for metals between total metal concentration and the adsorption coefficient (K_d) may not be linear for the chemical system of interest. MULTIMED is not capable of incorporating non-linear adsorption coefficients and can accommodate only a single K_d value that is applied regardless of metal concentration. Because a single K_d value must be used and a linear relationship assumed, the user should select a value that is conservative and not likely to overestimate actual adsorption, and yet, is also realistic.

The user should first generate linear adsorption isotherm using a geochemical speciation model, such as MINTEQA2 (Allison et al., 1991), and then select the specific K_d value from the isotherm that corresponds to a threshold dissolved metal concentration. The threshold chosen can be the expected maximum concentration in the leachate and should be based on metal concentrations detected in leachate from representative landfills.

3.2.4 Limitations of the MULTIMED Model for Low Hydraulic Conductivity Aquifers

Experience has shown that the MULTIMED model may not be not appropriate for some modeling scenarios that include a saturated zone with a low hydraulic conductivity. Specifically, if the hydraulic conductivity is very low, the model may not be capable of mathematically transmitting the infiltrating leachate through the aquifer, so the model may issue a warning message in the output file. The warning message, "Near Field Mixing Factor less than 1.0",

indicates that the aquifer characteristics input to MULTIMED are such that the aquifer cannot transmit all of the water that the HELP model predicts is reaching the water table. When this occurs, the user should evaluate the following issues:

- evaluate the infiltration rate and recharge rate predicted by HELP to ensure that it is reasonable for the proposed design; and

- reexamine the aquifer data input to MULTIMED (hydraulic conductivity, hydraulic gradient, etc.) to determine if they are reasonable (within the known range of values for each parameter) and representative of the aquifer or aquifers over which the proposed landfill liner design will be located.

In some cases, the interpretation of the warning is that too much leachate is being released from the landfill. An alternative liner design that results in a lower infiltration rate may be necessary. Alternatively, the MULTIMED warning message could imply that the value of hydraulic conductivity is too low and may not be representative of the uppermost aquifer beneath the proposed landfill site. For example, if the input value for hydraulic conductivity is based on only one or two field measurements, additional data may be required to assure that a representative hydraulic conductivity value is input to the MULTIMED model.

3.2.5 Use of Monte Carlo Simulations

MULTIMED can be run in deterministic or Monte Carlo mode. The deterministic mode generally is used when the input parameters exhibit a narrow range of variability or the analysis is site specific. The deterministic mode is used to produce one model result (DAF) for one set of input values. However, when a large number of the input parameters exhibit a high degree of variability, it may be appropriate to use a Monte Carlo simulation. Monte Carlo simulations consist of a large number of computer runs that use randomly drawn values for selected input parameters. Monte Carlo simulations are used to account for the variability in input parameter values and combinations of these values that may be encountered. The number of simulations in a Monte Carlo evaluation should depend on the number of parameters being varied and the degree of variability or uncertainty in the parameters, as discussed in the User Manual Supplement (Allison, 1993).

Estimating Statistical Distributions for Each Input Parameter

The use of the Monte Carlo simulation mode in MULTIMED requires statistical values for each parameter, including the **type of statistical distribution** and **minimum**, **maximum**, and **mean** or **median** values depending on the type of statistical distribution. MULTIMED allows the user to select from a list of default statistical distributions for each parameter. In addition, some of the default values are based on EPA survey data that include summary statistics. Additional detail on the use of Monte Carlo simulations is provided in the MULTIMED Application Manual (Sharp-Hansen, et al., 1990).

Selecting a Receptor Well Concentration/DAF Percentile

The output of a MULTIMED Monte Carlo simulation includes a set of statistical parameters that describe the distribution of concentrations at the POC for the series of simulations performed. These statistical parameters include the **number of simulations**, the

mean, standard deviation, coefficient of variation, and **maximum and minimum values of receptor well concentration.** The output also includes **percentiles of the cumulative frequency distribution** that consist of estimated well concentrations ranked from lowest to highest. The predicted concentration using the 100th percentile of the cumulative frequency distribution is the highest predicted concentration, therefore it represents the most conservative estimate of the DAF predicted by the model. However, other percentiles (e.g. 90th or 85th percentile) may be selected if the user can provide sufficient justification that the use of that percentile is conservative. Selection of an appropriate percentile is described in the User Manual Supplement (Allison, 1993).

3.2.6 Use of Total vs. Net Precipitation to Determine Ground-Water Recharge Rate

MULTIMED requires as input a value for **ground-water recharge rate.** This parameter represents the rate of ground-water infiltration into the aquifer downgradient of the landfill. The User Manual Supplement (Allison, 1993) states that this parameter can be determined from field observations, from applying the HELP model without using the engineering design of the landfill (computing infiltration through the undisturbed land surface in the vicinity of the landfill), or by using a fraction of the precipitation rate computed with HELP. Using the total precipitation computed by HELP would not account for evapotranspiration and, therefore, would overestimate the amount of ground-water recharge. The result would be a non-conservative estimate of contaminant dilution in the aquifer. A more conservative alternative would be to use net precipitation, which would consist of subtracting evapotranspiration computed by HELP from the total precipitation rate computed by HELP. The most conservative assumption would be to set this parameter to zero.

3.3 Interpreting MULTIMED Results -- Use of the Dilution/Attenuation Factor (DAF)

The output from the MULTIMED model is the estimated concentration of a contaminant at a downgradient receptor well. This value is used to determine the amount of dilution and attenuation (dilution/attenuation factor or DAF) that a contaminant will undergo as it is transported from the base of the landfill to a downgradient receptor well. To determine if contaminant concentrations will exceed the performance standard at the POC, the user must determine representative concentrations of contaminants in landfill leachate. Data sources and issues associated with identifying representative values are discussed in the following sections.

The concentration of each contaminant in the leachate is divided by the DAF to determine the expected concentration in drinking water at the receptor well. Analytical leachate data may be available in the form of site-specific data based on analysis of leachate from existing landfills, statewide averages of contaminant concentrations, or nationwide values obtained from EPA surveys. Issues related to use of these data sources are addressed in the following sections.

3.3.1 Use of Site-Specific Leachate Data

For the review of permit applications that address a single facility, site-specific data may be available that can be used for the MULTIMED analysis. For example, some permit applications were submitted for expansions to existing landfills. In these cases, analytical leachate data were available for the existing landfill cells. The EPA assumed that these analytical leachate

data are representative of the leachate that would be generated in the new portion of the landfills for which the permit applications were submitted.

3.3.2 Use of Statewide Average Values or EPA Summary of Nationwide Data

In some cases, state permitting agencies may have on record leachate data for landfills throughout a state. And in some cases, statewide average or weighted representative values based on these data may be available that would be suitable for the evaluation of a proposed landfill design. If site-specific or statewide values for contaminant concentrations in leachate are not available, it may be necessary to use data that are based on nationwide analyses of landfill leachates. The Agency developed a summary of data on Municipal Solid Waste landfill leachate characteristics that contains statistics on concentrations of contaminants in landfill leachate (U.S. EPA, 1988). Some of these data are from relatively old landfills; landfill owners/operators should use data from newer, more representative landfills where possible.

3.3.3 Using Detection Limits vs. Detectable Concentrations

Analytical leachate data may indicate that some contaminants were measured at concentrations that are below the detection limit. In these cases, the most conservative approach for evaluating a design would be to use the detection limit value for those contaminants. However, if a State/Tribe can provide sufficient evidence that the contaminant would never be expected to appear in leachate, the user may elect to exclude those contaminants that are below detection limits.

4.0 Conclusion

A landfill design meets the Subtitle D performance standard when the concentration of each contaminant at the POC is less than the performance standard for that contaminant. If the design does not meet the performance standard based on the results of the HELP/MULTIMED analysis, it may be necessary to modify the landfill design to reduce the rate of infiltration from the bottom of the landfill. The new landfill liner design then needs to be reevaluated. This process of proposing a design, evaluating the design with HELP to estimate the infiltration rate, and using the infiltration rate in MULTIMED to determine if the design meets the performance standard, should continue until a landfill design is developed that meets the performance standard.

REFERENCES

Allison, J.D. 1993. User manual Supplement: Using MULTIMED to Evaluate Subtitle D Landfill Designs, U.S. Environmental Protection Agency, Office of Solid Waste, Washington, DC.

Allison, J.D., D.S. Brown, and K.J. Novo-Gradac. 1991. MINTEQA2/PRODEFA2, A Geochemical Assessment Model for Environmental Systems, Version 3.0 User's Manual. EPA/600/3-91/021. U.S. Environmental Protection Agency, Athens, GA.

Einfeld, C.G., et al. 1982. "Approximating Pollutant Transport to Ground Water," Ground Water 20 (6), 711-722.

Giroud, J.P., K. Badu-Tweneboah, and R. Bonaparte. 1992. "Rate of Leakage through a Composite Liner Due to Geomembrane Defects," Geotextiles and Geomembranes 11(1), 1-28.

Giroud, J.P., and R. Bonaparte. 1989. "Leakage through Liners Constructed with Geomembrane Liners -- Parts I and II and Technical Note," Geotextiles and Geomembranes 8(1) 27-67, 8(2) 71-111, 8(4) 337-340.

Salhotra, A.M., P. Mineart, S. Sharp-Hansen, and T. Allison. 1990. "Multimedia Exposure Assessment Model (MULTIMED) for Evaluating the Land Disposal of Wastes -- Model Theory," U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, GA.

Schroeder, P.R., C.M. Lloyd, P.A. Zappi, and N.M. Aziz. 1994a. "The Hydrogeologic Evaluation of Landfill Performance (HELP) Model: User's Guide for Version 3," EPA/600/R-94/168a, U.S. Environmental Protection Agency Risk, Reduction Engineering Laboratory, Cincinnati, OH.

Schroeder, P.R., T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peyton. 1994b. "The Hydrogeologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3," EPA/600/R-94/168b. U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory. Cincinnati, OH.

Sharp-Hansen, S., C. Travers, P. Hummel and T. Allison. 1990. "A Subtitle D Landfill Application Manual for the Multimedia Exposure Assessment Model (MULTIMED)," U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, GA.

U.S. EPA. 1988. "Summary of Data on Municipal Solid Waste Landfill Leachate Characteristics." Draft Background Document

U.S. EPA. 1990. "Stability of Lined Slopes at Landfills and Surface Impoundments." EPA/600/S2-89/057. U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory. Cincinnati, OH.

U.S. EPA. 1992. "Evaluation of Subtitle D Landfill Designs Using the HELP and MULTIMED Models: A Tutorial," U.S. Environmental Protection Agency, Office of Solid Waste, Washington, DC, 20460.

U.S. EPA. 1994. "Seminar on Construction Quality Assurance/Construction Quality Control (CQA/CQC) for Waste Containment Facilities and Hydrologic Evaluation of Landfill Performance (HELP) Model," Philadelphia, PA, June 22-23, 1994. U.S. Environmental Protection Agency, Office of Research and Development, Technology Transfer.